

SPACELAB 3: RESEARCH IN MICROGRAVITY

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ABSTRACT

The Spacelab 3 mission, which focused on research in microgravity, took place during the period April 29 through May 6, 1985. Spacelab 3 was the second flight of the National Aeronautics and Space Administration's modular Shuttle-borne research facility. An overview of the mission is presented here. Preliminary scientific results from the mission were presented by investigators at a symposium held at Marshall Space Flight Center on December 4, 1985. This special issue is based on reports presented at that symposium.

INTRODUCTION

Spacelab 3, the second flight of the National Aeronautics and Space Administration's (NASA) orbital laboratory, signified a new era of research in space. The primary objective of the mission was to conduct applications, science, and technology experiments requiring the low-gravity environment of Earth orbit and stable vehicle attitude over an extended period (e.g., 6 days) with emphasis on materials processing. The mission was launched on April 29, 1985, aboard the Space Shuttle Challenger which landed a week later on May 6. The multidisciplinary payload included 15 investigations in five scientific fields: materials science, fluid dynamics, life sciences, astrophysics, and atmospheric science.

The basic Spacelab hardware for the mission included a pressurized long module and an Experiment Support Structure (ESS). The pressurized module provided a shirtsleeve environment where the payload crew conducted the experiments. The ESS provided a structure for mounting experiments which required direct exposure to space. Reference 1 provides additional details on the Spacelab 3 mission configuration. The first Spacelab mission in late 1983 verified that the facility provided a suitable environment for research activities in a variety of fields. With this assurance, the Spacelab 3 mission was dedicated solely to scientific experiments, with no further verification testing. (Spacelab 3 was actually the second flight of the laboratory because of delays in the development of a pointing system for the Spacelab 2 mission.)

The NASA Office of Space Science and Applications (OSSA) has overall responsibility for all NASA Spacelab and attached payload missions. The Spacelab 3 mission development and operation was managed and performed for OSSA by the NASA Marshall Space Flight Center (MSFC). Spacelab 3 investigations were selected by a peer review process and were judged on the basis of their intrinsic scientific merit and suitability for flight. Proposals for experiments came through several channels, including NASA Announcements of Opportunity that solicited research ideas from the worldwide scientific communities and agreements with foreign governments. NASA selected 15 investigations for flight, including 12 investigations from the United States, two from France, and one from India. Table 1 provides a list of the experiments and investigators by scientific discipline along with each investigations' acronym which will be used to refer to the instrument throughout this report.

Soon after selection, experimenters convened in an Investigators Working Group (IWG) that met periodically to guide the scientific planning for the mission. The IWG included the principal investigator for each experiment chosen for flight and was chaired by the mission scientist, Dr. G. Fichtl, from MSFC. The IWG was responsible for allocating resources to different experiments, organizing inflight science operations, and nominating and selecting payload specialists. Over the years, the IWG served as a valuable forum for resolving conflicting scientific interests.

The Spacelab 3 mission was designed and operated to provide the best low-gravity environment that could be achieved within the capabilities of Space Shuttle and Spacelab systems. The high quality microgravity environment was conducive to materials processing and fluid dynamics research and at the same time maximized the scientific return for the total payload. Five experiments – three in crystal growth and two in fluid mechanics – were extremely sensitive to gravity, vehicle accelerations, and maneuvers. Mission management gave careful consideration to the elements influencing the Spacelab environment. Maneuvers for an astronomical experiment were scheduled during the first 18 hours of the mission. For the remainder of the mission, the orbiter was maintained in a “gravity gradient” attitude with the tail pointed toward Earth, the wings oriented in the orbit plane, and the payload bay open to the Southern Hemisphere. Maintenance of this stable attitude required the least number of vernier control system thruster firings and, thus, reduced disturbance of the delicate experiments. The attitude was also suitable for the atmospheric and cosmic ray astronomical observations made by three other Spacelab 3 instruments. The particular flight attitude was also selected for a subtle reason which will be referenced later in a discussion of the fluid dynamics experiments. The materials science and fluid physics experiments were clustered around the center of mass of the vehicle, a location least affected by forces proportional to the distance from the center of mass.

The Spacelab 3 mission operations were managed by a MSFC ground control team working in the Payload Operations Control Center (POCC) at the Johnson Space Center (JSC). Science teams for each of the experiments worked in user rooms adjacent to the POCC and interacted with the payload science crew through the POCC communications system. Spacelab 3 demonstrated the value of direct communication between the science crew in space and the research teams on the ground. The mission set a record for downlinked video with over 3 million recorded images. The mission clearly demonstrated that Spacelab represents the merger of science and manned spaceflight. Scientists in space collaborated with their colleagues on the ground, solving problems and modifying experiments to enhance scientific yield.

Payload specialists (PS's) conducted the onboard scientific investigations. They were selected and trained by the Spacelab 3 principal investigators (PI's) and instrument facility developers. The flight payload specialists were Dr. Taylor Wang of the Jet Propulsion Laboratory in Pasadena, California, and Dr. Lodewijk van den Berg of the EG&G Corporation in Santa Barbara, California. The alternate PS's were Dr. Eugene Trinh of the Jet Propulsion Laboratory and Dr. Mary Helen Johnston of the Marshall Center. The alternate PS's supported the mission operations in the POCC. Dr. Wang was the principal investigator for the Drop Dynamics Module experiment (see below), and Dr. Trinh was a co-investigator for that experiment. Dr. van den Berg was a co-investigator for the Vapor Crystal Growth System experiment (see below).

These four scientists were selected for their specialized backgrounds and experience in materials sciences and fluid mechanics. Drs. van den Berg and Johnston are materials scientists with expertise in crystal growth, and Drs. Wang and Trinh are fluid dynamics experts. The flight payload crew consisted of the PS's and the mission specialists (MS's). The designated MS's included Drs. Don Lind, William Thornton, and Norman Thaggard. The flight crew was charged with operation of the Shuttle and was staffed by commander Col. Robert Overmyer and pilot Lt. Col. Frederick Gregory. The MS's were

responsible for conducting the interface operations between the Spacelab payload and the Shuttle orbiter and for operating selected science instruments. Mission specialist Lind was a co-investigator on the auroral observations experiment (see below).

Development of an around-the-clock schedule of events for the flight was a major task. Time is a critical resource on a week-long mission. All crew activities, experiment requirements, Spacelab resources, and Shuttle maneuvers were merged into an efficient daily 24-hour operating plan. The master schedule was designed to be revised in response to unexpected difficulties or opportunities, but the guiding philosophy was to adhere as closely as possible to the preflight timeline. As the mission neared, segments of the timeline were rehearsed using the integrated Spacelab hardware and simulators. These simulations prepared the crew, the scientists, and the management cadre for the mission.

The evolutionary nature of the approaching mission was illustrated as the payload was integrated from pieces into a complete scientific research laboratory. Individual instruments arrived at the Kennedy Space Center and were tested. Then they were placed in racks, floor-to-ceiling enclosures which fit inside the cylindrical Spacelab module. Five of the instruments were "minilabs," large instrument facilities that fill an entire rack and can remain assembled for easy reflight. Next, all 12 Spacelab racks installed in the floor were inserted into a habitable module which previously served as a shirtsleeve workshop for the first Spacelab mission. Two instruments were mounted outside the module on the multipurpose Experiment Support Structure (ESS), a lightweight payload carrier that bridged the width of the payload bay. Integrated payload tests were conducted on the ground in which instruments were operated by the crew and investigators. Kennedy Space Center technicians integrated the Spacelab 3 payload with Challenger, and the orbiter was moved to the launch pad.

MATERIALS SCIENCES EXPERIMENTS

The Spacelab 3 mission materials processing experiments were aimed at growing more homogeneous crystals by crystal seed growth research involving vapor transport (VCGS, MICG) and solution growth processes (FES) (see Table 1 for definition of acronyms). The motivation for performing these experiments on the Spacelab 3 mission was to reduce gravity-driven convection and eliminate or reduce imperfections resulting from gravitationally-induced strain fields and dislocations (VCGS) produced by the weight of the crystal when it is relatively weak during the growth process.

Solution Growth of Crystal in Zero Gravity (FES)

Two triglycine sulfate (TGS) crystals were grown by a low-temperature solution growth technique for growth times of 58 and 32.2 hours. The objectives were to (1) develop a technique (cooled sting) for solution crystal growth in a low-gravity environment, (2) characterize the growth environment provided by an orbiting spacecraft and assess the influence of the environment on the growth behavior, and (3) determine how growth in a low-gravity environment influences the properties of the resulting TGS crystal. For the first time in any spaceflight experiment, the growth was monitored onboard as well as on the ground by a specially developed video schlieren technique. Hundreds of holographic photographs were taken during the mission; image projection of the hologram has allowed investigators to observe solution/crystal interaction during the growth process. Preliminary results indicate that the optical system worked very well and the quality of the reconstructed holograms is satisfactory. The hardware performed as expected. The total growth for both crystals was less than predicted from theoretical calculations, but the quality of crystals appears to be quite good. Electrical measurements and fabrication of infrared detectors is in progress. Barnes Engineering Company in Stamford, Connecticut, is working as a guest industrial investigator by fabricating the infrared detectors from the flight crystals. TGS has

practical applications as a pyroelectric infrared detector. The crystals are the basis of advanced sensor systems for applications which include Earth resources surveying, pollution monitoring, thermal imaging for medical diagnostics, fire location detection, and infrared astronomy. Improved crystals (i.e., crystals with few imperfections) potentially resulting from spaceflight could result in improved detector capability.

Mercuric Iodide (HgI_2) Growth for Nuclear Detectors (VCGS)

The purpose of this investigation was to grow more perfect mercuric iodide crystals in a low-gravity environment by taking advantage of diffusion-controlled growth conditions and by avoiding the problem of strain dislocations produced by the crystal's weight. A single crystal was grown in this facility for approximately 120 hours. This experiment required extensive crew participation. The payload and mission specialists initiated the crystal growth process, monitored the growth phase through a microscope, and responded to crystal growth behavior by making changes in the hardware parameter settings.

After returning to Earth, the crystal grown in space was subjected to gamma-ray rocking curve diffraction measurements. The results obtained to date indicate that the space-grown crystal is of higher quality and more homogeneous than any mercuric iodide crystal grown thus far on the ground. Additional experiments will be made to determine the electronic properties of the space crystal and to evaluate the effect of reduced gravity on the vapor transport process. This crystal substance has considerable practical importance as a sensitive gamma-ray detector and energy spectrometer that can operate at room temperature. Presently, cumbersome cryogenic systems are used to cool available detectors to near liquid nitrogen temperatures. However, the performance of mercuric iodide crystals only rarely approaches the expected performance, presumably because some of the free electrical charges produced within the crystal are not collected at the electrodes but instead remain trapped or immobilized as crystal defects. An efficient high atomic number semiconductor detector that is capable of operating at room temperature utilizing single mercuric iodide crystals offers potential beyond existing detector technology.

Mercuric Iodide Crystal Growth (MICG)

The objective of this experiment was to study crystal seed and growth processes with the vapor crystal growth technique in two and three zone furnaces. The crystal material, mercuric iodide, is the same as that grown in the VCGS, and once again vapor growth process was used. In this experiment, the focus is on the location and number of nucleation sites as a function of temperature distribution and partial pressure of an inert host gas (argon). Six ampoules, approximately 20 cm long and 1.5 cm in diameter, were flown on Spacelab 3. A distribution in temperature is maintained between the ends of the ampoule with and without material sinks at the cold end. A Stefan flow of mercuric iodide occurs from the hot to the cold ends of the ampoule. Nucleation occurs on the walls in the cold zone (1/3 of ampoule). The number and location of these sites, as well as the crystal seeds, are the quantities of interest. The effect of argon gas is to increase the number of nucleation sites and reduce the growth rate. Two experiments were performed, each in sets of three ampoules. The facility was operated over the entire mission. This experiment builds upon knowledge gained from similar experiments performed with the same facility on the Spacelab 1 mission wherein the goal was to grow single large crystals. This furnace was automated and required with minimal crew interaction.

FLUID DYNAMICS EXPERIMENTS

The Spacelab 3 fluid dynamics experiments are aimed at the study of fundamental fluid dynamic processes associated with rotating and oscillating drops and convection in spherical geometry.

Geophysical Fluid Flow Cell Experiment (GFFC)

The primary objectives of the geophysical fluid flow experiments are to simulate large-scale baroclinic (density-stratified) flows which occur naturally in the atmospheres of rotating planets and stars and to gain insights concerning the large-scale nonlinear mechanics of global-scale geophysical flows in spherical geometry. In particular, the investigators hope to identify those external conditions related to fluid viscosity, rotation, gravity, etc., which allow qualitatively different modes of instability or waves in the model.

The experiments were accomplished with a rotating hemispherical shell of fluid wherein radial gravitational forces are simulated with electrical polarization forces created in a dielectric fluid by applying a radially directed voltage drop across the fluid. The GFFC provides a simulated gravitational field of approximately 0.1 g or less. Spaceflight is required to insure the spherical symmetry of the total "gravitational field" in the experiment; in a terrestrial laboratory, gravity will destroy the spherical symmetry of the "gravitational field" in the GFFC. Total experiment time was 103 hours. The observations of temperature fluctuations in the fluid indicate that strongly rotating bodies exhibit global-scale convective patterns that tend to align themselves in "Taylor columns" oriented parallel to the rotation axis. However, as the degree of thermal instability is increased, strong buoyancy-driven turbulence sets in at high latitudes. At very large heating rates (or high Rayleigh numbers), this polar convection spreads toward the equator and eradicates the Taylor columns. When the imposed radially unstable temperature gradient includes a latitudinal component, new spiral instabilities are observed. At high heating and high rotation, the Taylor columns reappear but interact strongly with mid-latitude motions. The experiments are in agreement with linear theory and numerical simulations that can be carried out at the least extreme thermal conditions (lower Rayleigh numbers) of the laboratory model [4].

It is interesting to note that a vehicle attitude in which the angular velocity vectors of the vehicle and the experiment convection cell are parallel is preferred to minimize precessionally-driven fluid motions from occurring in GFFC. The Spacelab 3 vehicle attitude satisfied this requirement.

Dynamics of Rotating and Oscillating Free Drops (DDM)

The experiments performed in the DDM provided the first experimental data on free rotating and oscillating drops. The DDM is a three-axis acoustic facility wherein liquid drops can be formed and excited to execute rotational and oscillatory motion. Spaceflight is required because very strong acoustic forces would be required in terrestrial-based experiments which in turn would introduce physical phenomena that would overwhelm the physics under investigation.

The DDM research conducted on Spacelab 3 has yielded the first concrete experimental evidence on the manipulation of liquid drops using acoustic radiation pressure forces in microgravity. Drops of water and water and glycerin mixtures were successfully deployed and captured by the acoustic potential well without introducing any significant static distortion on the samples. Rotation around a fixed axis of the drops was also induced through acoustic torque and has allowed a study of the equilibrium drop shape dependence on the rotation rate. Results of some shape oscillation sequences have also confirmed the feasibility of surface tension and viscosity measurement schemes.

The axisymmetric regime of a freely suspended rotating drop has been studied in detail using volumes ranging from 0.5 to 10 cc, with viscosities between 1 and 100 cSt, liquid density around 1.16 g/cc, and surface tension centered at 65 dynes/cm. Very repeatable results have been obtained for the spin-up rate, the critical rotation speed for bifurcation between axisymmetric and two-lobed shapes, the axial deformation dependence on the rotation rate, and finally for the critical velocity at fission. No experimental evidence for any transition to higher multi-lobed shapes have been obtained in this first set of experiments.

The experiments are of fundamental interest because they are the first controlled experiments to be performed on essentially free drops and thus provide the first experimental data for testing theoretical predictions. They also provide guidance for development of theoretical models. The experiments are also of practical interest because acoustic manipulation of liquids is a prime candidate for containerless processing applications in space.

LIFE SCIENCES EXPERIMENTS

The Spacelab 3 mission life sciences experiments were aimed at (1) verification of design and biocompatibility assessment of research animal holding facilities, (2) calibration and verification of a urine monitoring system, and (3) test and application of autogenic feedback processes as a counter-measure to space adaptation syndrome.

Ames Research Center Life Science Payload

In response to a recognized need for an in-flight animal housing facility to support Spacelab life sciences investigations, a Research Animal Holding Facility (RAHF) was developed. The Spacelab 3 mission provided an opportunity to perform an in-flight Verification Test (VT) of the RAHF. Lessons learned from the RAHF-VT and baseline performance data will be invaluable in preparation for subsequent dedicated life sciences missions.

The RAHF is designed to support animals ranging in size from rodents to small primates. It is anticipated that such a system will satisfy the experimental requirements of a great majority of prospective investigators working with commonly-used laboratory animals.

On Spacelab 3, one RAHF was dedicated to supporting two monkeys in separate cages while the other supported 24 rats. The primate RAHF has the capability to house four monkeys; however, because of a decision to fly monkeys free of herpes virus Samuri only two monkeys were flown on this checkout mission. Over the 7-day flight, food and water were dispensed automatically. A photocell method was used to record animal activity. Four of the rats were monitored by a biotelemetry system (BTS) which recorded deep body temperature, heart rate, and waveform. Four rats were intermittently photographed during the mission by a movie camera programmed at given frame rates; the film was used to assess behavioral response to launch/recovery conditions and to weightlessness. The environment was automatically monitored and controlled for factors such as temperature, humidity, and airflow. During ascent and entry a dynamic environment measuring system (DEMS) was used to measure noise, vibration, and acceleration forces in the vicinity of the RAHF.

The RAHF worked very well, with some exceptions involving particulate release. The rats and monkeys were recovered unstressed, in excellent condition, and microbiologically clean. This information allows us to state that the RAHF maintains animals in a manner analogous to vivarium animals in laboratories and permits support of animal research in space in a realistic manner.

While the data is only partially reduced at this point, much information has already been obtained on the animals. One monkey demonstrated symptoms of space adaptation syndrome while the other did not. The rats returned to Earth with the following changes: they were flaccid, showing a marked decrease of muscle tone; marked loss of muscle and fiber diameter; reduced activity of the Krebs cycle in the muscle; hemorrhaging in one muscle; marked decrease in bone mass and a decrease in elasticity and breaking strength; a decrease in prolactin producing cells and an increase in growth hormone producing cells (however, little growth hormone was released postflight); and an increase in the hematopoietic system sensitivity in epthyropoietin. As data analyses are completed, it is expected that this mission will yield the greatest amount of information ever obtained from a biological payload in space and may well be the most significant contribution on biological systems in space ever gained from a single mission.

Urine Monitoring Investigation (UMS)

This investigation was designed to evaluate the UMS and to monitor the urine biochemistry of the crew. The primary objectives of the Urine Monitoring Investigation were (1) to verify the operation of the Urine Monitoring System (UMS) in the collection and sampling of urine, (2) to perform in-flight calibration of the UMS, (3) to estimate the crew members' ratio of fluid intake to urine output, and (4) to measure the effects of microgravity on a number of biochemical constituents of urine. Subsequent dedicated life sciences missions are anticipated to incorporate the UMS in support of a number of experiments which will be directed at studying fluid/electrolyte disturbances and related effects resulting from low-gravity exposure. Because of insufficient air flow through the UMS, only a few urine samples were collected for postflight analysis, and the limited number of samples precluded the physiological study of the sample. The calibration and testing objectives of the investigation were completed.

Autogenic Feedback Training

The objective of this experiment was to test the effectiveness of the combined use of autogenic and biofeedback training as a countermeasure to space adaptation syndrome (SAS) and to gain basic physiological data associated with SAS. Autogenic feedback training is a procedure that enables human subjects to gain voluntary control of several physiological responses simultaneously. Autogenic and biofeedback training, when used separately, do not appear to be effective countermeasures to motion sickness. However, it appears that a combination of these two techniques for control of bodily responses yields a powerful countermeasure to SAS which can be learned in a relatively short period of time. The principal investigator at the NASA Ames Research Center has obtained excellent results in ground-based rotating chair experiments for subjects with a wide-range of susceptibility to motion sickness. The Spacelab 3 mission AFT experiments involved the flight payload specialists as subjects and two of the mission specialists as controls. The subjects were given exercises to practice in the event of discomfort.

During their awake periods, both subjects and controls were instrumented with sensors to measure and record heart rate, body temperature, galvanic skin response, air volume, and breathing rate. These data were presented to the subjects on a wrist readout and used during AFT exercises by the subjects in response to discomfort associated with space adaptation as well as during routinely scheduled exercises to prevent SAS. Analysis of the Spacelab 3 AFT results is now underway.

ATMOSPHERIC OBSERVATIONS

The Spacelab 3 mission environmental observation experiments are aimed at the (1) measurement of atmospheric minor and trace species and (2) observation of southern aurora from a Spacelab orbit vantage point.

Atmospheric Trace Molecule Spectroscopy (ATMOS)

This investigation was designed to obtain fundamental information related to the chemistry and physics of Earth's upper atmosphere using the techniques of infrared absorption spectroscopy. There are two principal objectives. The first is the determination, on a global scale, of the compositional structure of the upper atmosphere and its spatial variability. The establishment of this variability represents the first step toward determining the characteristic residence times for upper atmosphere constituents, the magnitudes of their sources and sinks, and, ultimately, an understanding of their effects on the stability of the stratosphere. The second objective is to provide the necessary high-resolution, calibrated spectral information required for detailed design of advanced instrumentation for global monitoring of specific species.

The experimental approach for acquiring the data from Spacelab was to view the Sun with the ATMOS instrument during the periods just prior to entry into, and shortly after emerging from, a solar occultation. Specifically, the viewing periods were timed to occur when the ATMOS instrument's view of the Sun was occulted by the upper atmosphere. During these periods, the instrument made a set of interferometric measurements of the solar radiation incident as a function of optical path difference within the instrument. Subsequent Fourier transformation of these measurements produced spectra of the solar continuum between 2 and 16 μm with a resolution of 0.02 cm^{-1} . The characteristic absorption features are associated with stratospheric layers approximately 2 km thickness.

The instrument operated superbly. A total of 20 occultations were taken encompassing altitudes from approximately 5 to 120 km.

Preliminary analysis of the data has revealed the presence of more than 30 different molecular species whose concentrations can be measured over altitude ranges that vary, depending on the particular constituent, from the upper troposphere through the stratosphere and mesosphere to the lower thermosphere (approximately 130 km). Several of the trace constituents (for example N_2O_5 and ClONO_2) have not previously been detected with certainty. The stratospheric spectra provide simultaneous measurements of most of the species of importance in the nitrogen, chlorine, and hydrogen families of molecules involved in the ozone photochemistry of this region; the observations of the mesosphere and thermosphere, which include measurements of CH_4 , CO_2 , CO , H_2O , and O_3 , provide new insights into the photochemistry and dynamics of the region of the atmosphere characterized by dissociation of the minor gases and by the effects of the breakdown of local thermodynamic equilibrium [5].

In addition to the telluric spectra, the Spacelab 3 ATMOS flight returned a sufficient number of high resolution solar spectra to produce a very high signal-to-noise ratio solar atlas of the near and mid-infrared wavelength region. When published, this atlas will show features of the Sun's photosphere and chromosphere that have not been previously observed. NASA plans to fly the ATMOS instrument at approximately yearly intervals for the next 10 to 15 years to provide an archive of the composition of the upper atmosphere and its variability. The data will provide a valuable record to aid in the assessment of long-term changes in the properties of the atmosphere.

Auroral Observations

The Spacelab 3 mission provided a unique opportunity to make detailed observations of Southern Hemisphere aurora from space. Observations of aurora are available from the ground and from space looking downward from satellites (Dynamics Explorer, Defense Meteorological Satellite Program, for example). However, systematic observations of aurora from a lateral vantage point like that provided by

the Spacelab 3 mission orbit with 57 deg inclination and sufficiently large angle (angle between the Sun-Earth line and vehicle orbit plane) to penetrate the average auroral oval in darkness were not available previously. The typical aurora altitude is approximately 110 to 160 km and range in vertical extent from approximately 15 to 50 km. Thus, with a 350 km orbit altitude and range to the aurora target from Spacelab of 0 to 800 km, the viewing perspective varies from a downward looking one to a sideward looking one approximately 20 deg above the aurora. The orbiter's video imager was used to acquire five hours of data. The crew also took 274 color photographs. By using the orbital motion to provide the parallax, color photographs and the video recordings have been viewed stereoscopically.

The data provide the first views from outside the atmosphere of thin horizontal layers of "enhanced aurora." The layers, once thought to be rare, were recorded on two out of three passes. This first observation of enhanced aurora from space eliminates concerns that the ground-based observations might have been an optical illusion caused by atmospheric refraction. Also, for the first time, vertically thin layers were observed in diffuse aurora. This is a measurement that is possible only from space, ideally in near-Earth orbit.

ASTROPHYSICAL OBSERVATIONS

The Spacelab 3 mission astrophysics experiments were aimed at the (1) study of ionization states of solar and galactic cosmic ray heavy nuclei and (2) study of galactic and faint extragalactic sources and peculiar ultraviolet objects.

Cosmic Ray Experiment (IONS)

The Indian experiment, IONS (also called ANURADHA by the science team, ANURADHA is the Sanskrit name of the star Delta in Scorpius constellation), designed to measure the ionization states of low-energy galactic cosmic ray heavy nuclei, was highly successful on Spacelab 3. The flight period was characterized by (1) absence of solar flares and by (2) low-level of solar activity close to that of solar minimum. Therefore, the Spacelab 3 Mission was most favorable for the present studies of low-energy galactic cosmic ray heavy nuclei. The Anuradha experiment measures, in near Earth space, the flux, energy spectrum, arrival time, and direction of all heavy ions of all major elements, from helium to iron, of low energy cosmic rays, known as Anomalous Cosmic Rays (ACR) in the energy range of about 5 to 100 MeV/amu. From the arrival direction of heavy ions in space, the threshold magnetic rigidities (i.e., momentum/charge) of ions are determined using the computations of cosmic ray trajectories in geomagnetic field. By combining the data of magnetic rigidities with momentum of ions measured in the main detector, the ionization states of heavy ions are determined. The measurements of the ionization states, together with the abundances and energy spectra, will provide new clues to the origin of the ACR which is unknown at present.

From the initial studies of track density of cosmic ray events, it is calculated that the main detector has recorded high-quality events of about 10,000 particles and similar number of C, N, O and heavier ions of ACR. Analysis of the main detector stack is in progress.

Ultraviolet Astronomy Experiments (VWFC)

The proposed experiment was designed to study (1) large scale distribution of ultraviolet radiation in the Milky Way, (2) geometric extension of stellar clouds and spectral distribution, (3) diffusion of galactic light above the galactic plane (extension of galactic material), (4) sky background relative to

discrimination between galactic and extragalactic light and Sun light scattered by interplanetary dust (zodiacal light), and (5) spectral distribution of extended sources (as noted above) and nebular spectrography. Measurements were to be taken with a Schmidt camera which uses a 4 cm square photocathode proximity (diode) light intensifier to sense the incoming UV (1550-2300 angstroms) radiation. Three interference filters at wavelengths of 1550, 1900, and 2500 angstroms with a slit provided spectrograph capability. The instrument field of view is 54 deg with angular resolution of 3 arc minutes. The instrument was designed to operate out of the scientific air lock after sunset. Six targets were planned for this mission. This instrument flew on the Spacelab 1 mission and acquired data on the lower half of the celestial sphere. The Spacelab 3 mission targets were primarily located in the northern half of the celestial sphere [3].

Because of a malfunction of the Spacelab scientific air lock, it was not possible to carry out this investigation.

SUMMARY

The Spacelab 3 mission, by any measure, was an outstanding success. We have learned how to utilize the Shuttle/Spacelab system to provide the best low-gravity environment achievable from this system. This knowledge is being used in the development of Space Station and low-gravity facilities. The Spacelab 3 mission is a model for designing and operating future low-gravity Spacelab missions. Much of the research begun on Spacelab 3 will continue on future Spacelab missions and will help set the stage for research aboard Space Station.

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TABLE 1. SPACELAB MISSION 3 PAYLOAD

Discipline	Title	Acronym	Principal Investigator	Institution
Materials Science	Fluid Experiment System	FES	Dr. R. Lal	Alabama A&M University
	Vapor Crystal Growth System	VCGS	Mr. W. Schnepfle	EG&G, Goleta, California
	Mercury Iodide Crystal Growth (Reimbursable)	MICG	Dr. R. Cadoret	Laboratoire Physique des Milieux Condense's, France
Fluid Dynamics	Drop Dynamics Module	DDM	Dr. T. Wang	Jet Propulsion Laboratory
	Geophysical Fluid Flow Cell	GFCC	Dr. J. Hart	University of Colorado
Life Sciences	Ames Research Center Life Sciences Single Rack	RAHF	Dr. C. Schatte	NASA Ames Research Center
	- Primate Research Animal Holding Facility (RAHF) Verification Test			
	Double Rack			
	- Rodent Research Animal Holding Facility (RAHF) Verification Test	RAHF		
	- Biotelemetry System	BTS		
	- Dynamic Environment Measurement System	DEMS		
	Autogenic Feedback Training Experiment	AFT	Dr. P. Cowings	NASA Ames Research Center
	Urine Monitoring Investigation	UMI	Dr. C. Leach-Huntoon	NASA Johnson Space Center
	Atmospheric Trace Molecules Spectroscopy	ATMOS	Dr. C. Farmer	Jet Propulsion Laboratory
	Auroral Observations	Aurora	Dr. T. Hallinan	Geophysical Institute Fairbanks, Alaska
Astrophysics	Ionization States of Solar and Galactic Cosmic Ray Heavy Nuclei	IONS	Dr. S. Biswas	Tata Institute of Fundamental Research, India
	Very Wide Field Camera	VWFC	Dr. G. Courtes	Laboratoire D'Astronomie Spatiale, France